Establishing correspondence and traceability between wafers and solar cells

The present invention is related to production of solar cells, and more precisely to a method and a system for establishing correspondence between wafers and solar cells produced from said wafers, to provide solar cell traceability.

A solar cell panel comprises a matrix of solar cells, which convert sun light into electricity. Each solar cell is produced by treating a silicon wafer. Silicon wafers are cut out of a large silicon body called ingot.

The ingot is manufactured in a furnace, and good care is taken to control among other things the ingot's temperature during manufacturing, since it plays a very important role in defining the quality of the ingot.

A large ingot has normally an uneven quality. This uneven quality is reflected in the wafers cut from the ingot and in the cells, and it will lie as a bottom line governing the wafer and cell characteristics.

Cell quality can be measured swiftly and reliably. Usually cell quality is determined by means of an inspection, where the cell's surface, current, voltage, efficiency and shunt resistance are measured. Ingot and wafer quality can not be measured as precisely as cell quality, and a full characterization of wafer and ingot quality always includes cell processing of the materials. Detailed wafer and ingot quality measurements are very costly and require several weeks of testing, which makes them unsuitable for a production process.

The invention has thus as an object to provide a method for establishing correspondence between a cell and a wafer, that is, identifying which cell is produced from which wafer.

By means of the invention cell quality will easily be correlated to wafer and ingot quality and the furnace and other production parameters can be modified to increase the electrical quality and mechanical strength of both wafers and cells.

There are several methods for tracing a cell back to a wafer:

1) Wafer scribing/inking: An identification of the wafer is written on the wafer's surface by means of a marker, as described in e.g. US 6,482,661. A plurality of wafers are sliced from the ingot with a portion of the ingot indicia. Wafer indicia is then marked on the peripheral edge of the wafer. Said indicia is read by means of a camera and information is stored. JP 10321690 describes a method where a wafer number is printed in the peripheral part of a surface where a pattern is not formed. The wafer number is read by means of a CCD camera and recognized by a recognizing part. These methods have the disadvantage that they

lead to reduction in the wafer's surface quality. They are besides not suitable for mass production.

2) A small cut is performed on the wafer. This method leads to increased breakage ratio.

3) Tracking by means of advanced data systems (e.g. as described in US 6,330,971) which "follow" a wafer during all the process. This alternative is highly expensive as it requires adapting the tracking system to equipment produced by different entities.

Alternatives 1) and 2) are presently only used in the field of research. Alternative 3) is possibly used for very high amounts of cells, where the size of the batches justifies a high investment in tracking system, but to the applicant's knowledge this is not used in mass production today.

The invention has as an aim to provide a method and a system which do not modify the wafer's surface, and at the same time do not require adapting the tracking system to different pieces of equipment.

This object is achieved by means of a method and a system for establishing correspondence between wafers and solar cells produced from said wafers. Said method comprises, for each wafer and each solar cell,
a) providing an image of the wafer,
b) providing an image of the cell,
c) comparing the wafer image to the cell image,
d) upon match between a cell image and a wafer image, assigning the current cell to the current wafer.

The invention is based on the concept that the crystallographic structure is unique for each wafer, and that this structure is visible both in the wafer and in the manufactured cell, so that crystallographic image information is sufficient to establish a correspondence between a cell and a wafer.

According to one aspect of the invention, the steps a) and b) in the above mentioned method comprise depicting the crystallographic structure of the wafer and the cell, while step c) comprises comparing said crystallographic structures to one another.

No identification is applied to the wafer surface, since the wafer's and the cell's own appearance due to their crystallographic properties are used for identification.

Once a correspondence is established, it can e.g. be used to assign wafer data to each cell. According to one aspect of the method disclosed, it comprises linking wafer identification data to the corresponding cell.

If breakage of a wafer occurs during cell manufacturing, that particular wafer will be removed from the production line and there will not be a cell image matching the wafer image of that wafer. If no cell image match a particular wafer image, this wafer is thus assumed to be broken.

According to another aspect, the method permits determining quality for different sections of an ingot, where each section corresponds to one wafer. In this embodiment, the method comprises: assigning inspection data to each cell, assigning a wafer position (in the ingot) to each wafer, and upon match between a cell image and a wafer image, assigning cell inspection data to each wafer position in the ingot. These cell inspection data may include breakage of wafer during production process.

Assigning wafer position to each wafer and also inspection data to each cell are current procedures in the field of solar cell production and will thus not be discussed in detail.

Ingot quality data for each section (wafer) which are derived from this process, will permit analysis of the ingot's production process. A feedback system can then be implemented for adjusting process variables to obtain even good quality in the ingot. According to this, one aspect of the invention comprises adjusting ingot and/or wafer production parameters based on cell inspection data.

The method according to the invention requires provision of cell and wafer images. These images can be provided by means of at least one CCD camera, a CMOS camera, a digital camera, an IR depicting system or any other depicting system. The suitable system has to have a sufficient definition/resolution to provide an almost unique crystallographic image for each wafer/cell.

There may be several imaging devices arranged in different locations in the production process. This will provide more detailed information of the quality of the manufacturing steps, and thus enable more precise adjustments of the process variables.

According to another aspect, the method permits determining quality (electrical and mechanical) for different production equipment in the wafer and cell production processes. In this embodiment, the method comprises: assigning inspection data to each cell, assigning substantially complete manufacturing history to each wafer, and upon match between a cell image and a wafer image, including cell inspection data in each wafer manufacturing history.

Image data will be achieved by means of "fingerprint matching" software, that is image recognition software available in the market.

It is possible to implement one embodiment of the method where correspondence is established by means of image matching together with other methods, for example data tracking of the wafers. In this case, as the methods will complement one another, it will be possible to achieve satisfactory results without requiring high definition in the imaging system nor a complete data tracking.

By means of the invention it is also possible to create a database comprising cell/wafer images which are stored independently or linked to one another. Such a database will be highly useful for e.g. computing statistics. According to this, in one aspect, the method comprises storing the wafer image and the cell image in a memory before and/or after assigning the current cell to the current wafer.

The invention comprises also a method for controlling production parameters in a solar cell and/or wafer production process, comprising, apart from the above mentioned:
- providing the ingot position data and/or manufacturing history for each wafer,
- providing inspection data for the cell,
- upon match between a cell image and a wafer image, assigning the current cell's inspection data to the current wafer position in the ingot and/or the manufacturing history of the wafer.

This method provides ingot data related to each wafer position in the ingot.

In one aspect, the latter method comprises regulating ingot and/or wafer production based on cell inspection data assigned to wafer manufacturing history and identity, e.g. wafer position in ingot and other elements of the wafer manufacturing history. Of course it will be possible to use these parameters also for controlling cell production.

The cell inspection data may include wafer breakage as noted above.

The invention comprises also a system for establishing correspondence between wafers and solar cells produced from said wafers, comprising:
- at least one imaging device for providing images of the wafers and the cells,
- a processing unit for comparing a wafer image to a cell image, and upon match between a cell image and a wafer image, assigning the current cell to the current wafer, and
- a memory unit.

In one aspect of the invention the imaging device is adapted to provide images of the crystallographic structure of the wafer and the cell and the processing unit is adapted to compare the crystallographic structure of the wafer and the cell to one another.

The term "imaging device" refers here to all equipment which is necessary to provide an image depicting the crystallographic structure, that is not only devices adapted to provide an image but also hardware devices adapted to process said image in order to provide crystallographic information regarding the wafer and the cell.

In one aspect of the invention the processing unit is adapted to assign wafer identification data to the corresponding cell. Wafer identification data can be inputted to the processing unit by known means, e.g. a personal computer or another user interface devices.

In another aspect the processing unit is connected to a cell inspection unit providing cell inspection data, and is adapted to
- assign inspection data to each cell,
- assign a wafer position to each wafer, and
- upon match between a cell image and a wafer image, assign cell inspection data to each wafer position.

If breakage of a wafer occurs during cell manufacturing, that particular wafer will be removed from the production line and there will not be a cell image matching the wafer image of that wafer. If no cell image match a particular wafer image, this wafer is assumed to be broken.

It is also possible for the processing unit to receive cell inspection data via a manual input device (operator input) or other types of input devices (data file).

In a further aspect of the invention, the processing unit is connected to devices for ingot and/or wafer production control. In a further aspect, it is adapted to adjust ingot and/or wafer production parameters based on cell inspection data.

The cell inspection data may include wafer breakage as noted above.

In a further aspect of the invention, the system comprises two imaging devices.

Said imaging device(s) can be alike or different, and can be implemented, both in the case where a single device is used and where two devices are used by means of a CCD camera, a digital camera or an IR depicting system. One image device can be used for depicting the wafer while the other can be used for depicting the cell.

There may be even more imaging devices arranged in different locations in the production process to provide more detailed information of the different manufacturing steps. This will enable more precise adjustments of the process variables.

In one embodiment of the invention, the memory unit is adapted to store the wafer image and the cell image in a memory before and/or after a cell is assigned to a wafer.

The invention comprises also a system as mentioned above and adapted for controlling production parameters in a solar cell production process, comprising:
- a unit for providing wafer position data and/or manufacturing history,
- a cell inspection unit for providing inspection data for each cell,
where the processing unit in the system is adapted for, upon a match between a cell image and a wafer image, assigning the current cell's inspection data to the current wafer and/or wafer position.

According to one aspect of this system, the processing unit is adapted to regulate ingot and/or wafer production based on cell inspection data assigned to wafers and/or wafer positions.

The invention will now be described by means of an example illustrated in the drawings, where:

figure 1 is a block diagram illustrating an example of wafer manufacture,
figure 2 is a block diagram illustrating an example of cell manufacturing,
figure 3 is a block diagram illustrating one embodiment of the invention,
figure 4 is an example of a wafer image, and
figure 5 is an example of a cell image.

Figure 1 is a block diagram illustrating wafer manufacture. The point of departure (step 101) is a silicon ingot 1. This ingot is first sectioned into smaller ingots 2 (step 102), and these are sawed (step 103) by means of wire saws into wafers 3 (step 104). As one can see, the grain structure of the wafer is not modified during this production process.

Figure 2 shows the cell manufacturing process, and imaging devices 4 and 5 for providing images of the wafer and the cells. The process starts with wafers 3 which were cut out from ingot 1 in figure 1. In step 201, the wafers are subject to etching and texturisation, in step 202 a phosphorus doping is performed, in step 203 the edges of the wafers are etched, in step 204 the oxide layer on the wafer is removed. In step 205 an anti reflective coating is applied on the surface. After these steps, the wafer enters a screen printing line. In this screen printing line, the wafer is processed by means of a first printer (step 206), a first dryer (step 207), a second printer (step 208) and a second dryer (step 209). After this follows a third printer (step 210) and a sintering process in a furnace (step 211) followed by a cell sorting procedure (step 212). When the cells are finished, a quality control is performed (step 213).

As shown in the figure, a first imaging device 4, in this case a camera, is adapted to provide an image of each wafer before the cell manufacturing process starts. During the sorting step, an image of each cell is provided by means of a second imaging device 5.

Figure 3 shows an embodiment of the system according to the invention. Said system comprises:

- one or several imaging devices 4, 5 for providing wafer and cell images,
- a unit 6 for providing wafer position data, the function of this unit being to provide data regarding original position of each wafer in an ingot,
- a cell inspection unit 7 for providing inspection data for each cell, this cell inspection unit performs the quality control operation in step 213 in figure 2,
- a processing unit for comparing each wafer image to a cell image to identify the original wafer for each cell and for assigning cell inspection data to the corresponding wafer and/or wafer position,
- a memory unit (9) for storage of processing instructions and data.

In one embodiment of the system, the processing unit is adapted to regulate ingot and/or wafer production (IPP, WPP) based on cell inspection data assigned to wafers and/or wafer positions. This is shown in figure 3, where processing unit 8 can control the ingot production process directly, or via a production process input device 9 can send commands to processing unit(s) which control the ingot and wafer production process. Although it is not shown in the figure, it is also possible to control cell production process (CPP) by means of processing unit 8.

The system can also comprise a user interface 10 for input of commands and data regarding ingot/wafer/cell, and a display for communication with a user.

Figure 3 shows also in which steps of the process data regarding ingot/wafer/cell are collected, where this data comprises wafer and cell image, wafer position information, cell inspection data, etc.

As one can see, the invention provides reliable and swift feedback regarding process quality and permits thus adjustment of process parameters to achieve a better result.

Figure 4 shows an image of a wafer before start of the manufacturing process, and figure 5 shows an image of a cell resulting from the manufacturing process. As one can see, the crystallographic structure can clearly be recognized in the images, and this structure will be unique for each wafer and the corresponding cell.